

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of : Atty. Docket: 02-CA-068/GC  
Adalberto MARIANI et al. : Group Art Unit: 2817  
Serial No. 10/612,335 : Confirmation No. 3783  
Filed: July 2, 2003 :  
For: FREQUENCY/SIGNAL CONVERTER AND SWITCHING  
REGULATOR HAVING SUCH A CONVERTER

**CLAIM FOR PRIORITY UNDER 35 USC §119**

Commissioner for Patents  
P.O. Box 1450  
Alexandria, VA 22313-1450


SIR:

Under the provisions of 35 USC §119, there is filed herewith a certified copy of European Application No. 02425435.1 filed on July 2, 2002, in accordance with the International Convention for the Protection of Industrial Property, 53 Stat. 1748, under which Applicants hereby claim priority.

Respectfully submitted,

Date: 11/21/03

By:

  
Stephen Bongini  
Reg. No. 40,917  
Jan Gibbons  
37,333

Customer No. 23334  
Fleit, Kain, Gibbons, Gutman, Bongini & Bianco P.L.  
551 NW 77th Street  
Suite 111  
Boca Raton, Florida 33487  
Telephone: (561) 989-9811  
Facsimile: (561) 989-9812  
claimforpriority.wpd



1954-55  
1954-55

1954-55



**Europäisches  
Patentamt**

**European  
Patent Office**

**Office européen  
des brevets**

**Bescheinigung**

**Certificate**

**Attestation**

Die angehefteten Unterla-  
gen stimmen mit der  
ursprünglich eingereichten  
Fassung der auf dem näch-  
sten Blatt bezeichneten  
europäischen Patentanmel-  
dung überein.

The attached documents  
are exact copies of the  
European patent application  
described on the following  
page, as originally filed.

Les documents fixés à  
cette attestation sont  
conformes à la version  
initialement déposée de  
la demande de brevet  
européen spécifiée à la  
page suivante.

**Patentanmeldung Nr.    Patent application No.    Demande de brevet n°**

02425435.1

Der Präsident des Europäischen Patentamts;  
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets  
p.o.

**R C van Dijk**





Anmeldung Nr:  
Application no.: 02425435.1  
Demande no:

Anmeldetag:  
Date of filing: 02.07.02  
Date de dépôt:

Anmelder/Applicant(s)/Demandeur(s):

STMicroelectronics S.r.l.  
Via C. Olivetti, 2  
20041 Agrate Brianza (Milano)  
ITALIE

Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:  
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.  
If no title is shown please refer to the description.  
Si aucun titre n'est indiqué se referer à la description.)

Frequency/signal converter and switching regulator employing said converter

In Anspruch genommene Priorität(en) / Priority(ies) claimed /Priorité(s)  
revendiquée(s)  
Staat/Tag/Aktenzeichen/State/Date/File no./Pays/Date/Numéro de dépôt:

Internationale Patentklassifikation/International Patent Classification/  
Classification internationale des brevets:

G05F1/00

Am Anmeldetag benannte Vertragstaaten/Contracting states designated at date of  
filing/Etats contractants désignées lors du dépôt:

AT BE BG CH CY CZ DE DK EE ES FI FR GB GR IE IT LI LU MC NL PT SE SK TR



"Frequency/signal converter and switching regulator employing said converter."

\* \* \* \* \*

#### DESCRIPTION

5           The present invention refers to a frequency/signal converter and to a switching regulator employing said converter.

          In electronic field circuits adapted to generate signals that are proportional to the clock frequency of electronic devices are often employed. Typically circuits employing known phase-locked loops (PLL)  
10       are used each comprising a phase detector of an input signal, a filter, an amplifier and a voltage controlled oscillator (VCO). When the lock occurs, the VCO control voltage is made proportional to the frequency of the input signal.

          The frequency/signal converters can be utilized in different  
15       applications as in the switching regulators. The lasts provide a substantially constant output voltage to a load from a fluctuating input voltage; the regulators comprise a switch, for example a transistor, coupled in series o in parallel with the load and a filter, usually a LC filter. Generally these  
20       transistors are driven by a circuitry controlling the turning off and the turning on of the transistor by means of the definition of a duty-cycle, that is the rate between the time that the switch is on and the switching time; said circuitry has usually an input clock signal deriving from an oscillator that fixes the switching time. A control circuitry placed in feedback between the output and the input of the regulator allows to make stable the output voltage  
25       against load variances and input voltage fluctuations.

          In the case of the current mode switching regulators, that is regulators controlled by a current signal, the control circuitry takes the current flowing through an inductance and compares it with a current deriving from a transconductance amplifier having in input the output voltage of the  
30       regulator and a voltage reference; the control circuitry acts on the turning on

and off circuitry of the transistor. The current mode switching regulators, when the duty-cycle exceeds 50%, become unstable; for this reason a slope compensation signal is injected into the current control signal.

5 A current mode switching regulator is described in the US patent 5929620. This switching regulator is synchronized by an external clock signal and comprises a PLL circuit that synchronizes the oscillator of its VCO with the external clock signal. The phase locked loop synchronizes the oscillator of the VCO without interfering with a slope compensation signal produced by the same VCO and which is added to the current control signal.  
10 The PLL circuit however is not stable and it is also necessary to make it stable by adding a compensation network.

In view of the state of the art described, it is an object of the present invention to provide a frequency/signal converter that is more simplex than the known devices.

15 According to the present invention, this object is attained by means of a frequency/signal converter capable of providing an electric signal at an output terminal by deriving it from an input clock signal, characterized by comprising first means having said clock signal in input and being capable of providing a first and a second logic output signals which are  
20 complementary with one another, a loop circuit comprising a first and a second circuit lines arranged between a first supply voltage and a second supply voltage where said first supply voltage is higher than said second supply voltage and wherein a current proportional to said output signal of said converter flows, said first and a second circuit lines comprising  
25 respectively first and second capacitive elements and second and third means which are adapted to interrupt the flow of said current into the capacitive elements and which are controlled by means of said first and second logic signals, said first and a second circuit lines being alternatively connected with an input terminal of an integrator device by means of other  
30 ones of said third and second means in order to obtain at said input terminal



a substantially constant voltage signal, said integrator device being adapted to provide said output signal of the converter.

Always according to present invention it is possible to provide a switching regulator as defined in claim 5.

5           Thanks to present invention it is possible to form a frequency/signal converter that is stable in se without adding a compensation network. Said converter can be used to generate a slope compensation signal in a switching regulator.

10           The features and the advantages of the present invention will be made evident by the following detailed description of an embodiment thereof, illustrated as not limiting example in the annexed drawings, wherein:

Figure 1 is a circuit scheme of a frequency/signal converter according to the present invention;

15           Figure 2 shows time diagrams of the signals Clk, PH1, PH2, RESET1, RESET2 which are employed in the converter in Figure 1;

Figure 3 shows the time waveforms of the output voltage signal  $V_{cur}$  and those at some nodes of the converter circuit in Figure 1;

Figure 4 is a circuit scheme of a current mode buck converter comprising the converter circuit in Figure 1;

20           Figure 5 shows the comparison between the signals  $I_l$  and  $I_{prog}$  in two time periods that are successive to each other;

Figure 6 shows the time diagrams of the signals  $I_l$  and  $I_{prog}$  which derive from simulations.

25           In Figure 1 a frequency/signal converter according to the present invention is shown. The circuit comprises a flip-flop 1 of the toggle type which is adapted to generate by means of a synchronization signal or clock signal Clk, that is a square wave signal having a period T which derives preferably from an oscillator, two logic signals PH1, PH2 which are complementary with each other in a time period 2T, and two pulse signals  
30           RESET1, RESET2 which are sensitive to the respective rise fronts of the

signals PH1 and PH2; said signals are shown in Figure 2.

The circuit comprises two lines A and B which have a respective switch couples 2, 3 and 4, 5; the lines A and B are in parallel to each other and are arranged in a supply path between a supply voltage VDD and ground. The line intermediate nodes C and H are connected with the terminals of two switch 6 and 7 which have the other terminals in common at the node G that is connected with the inverting input of a transconductance error operational amplifier 8 having a transconductance gain  $g_m$  and the non-inverting input connected with a voltage reference  $V_{ref}$ . The output current from the amplifier 8 is integrated by means of a capacitor  $C_{int}$ , connected between the output terminal of the amplifier 8 and ground, to achieve a voltage  $V_{cur}$  which in turn is in input to a transconductor circuit  $I_k$  adapted to generate a current  $I$ , which flows in the lines A and B, obtained by  $I = K_c \cdot V_{cur}$ . The nodes C and H are connected with two capacitor  $Cr_1$ ,  $Cr_2$  which have the same value  $Cr$  and the other terminals connected with ground.

The signals PH1 and PH2 drive respectively the switches 2, 7 and 4, 6 while the signals RESET1, RESET2 drive the switches 3 and 5. When the signal PH1 is at the logic level 1, after the pulse RESET1 has made discharged to ground the capacitor  $Cr_1$  by closing the switch 4, the same capacitor is charged by closing the switch 2 for a time period  $T$ ; the voltage at the node C is  $V_C = I \cdot T / Cr$ . When the signal PH2 is at the level logic 1 the voltage  $V_C$  is applied at the inverting input of the amplifier 8 and after the pulse RESET2 has made discharged to ground the capacitor  $Cr_2$  by closing the switch 5, the same capacitor is charged by closing the switch 3 for a time period  $T$ ; the voltage at the node H is always  $V_H = I \cdot T / Cr$ .

Therefore at the inverting input terminal of the amplifier 8 a voltage  $V_G = I \cdot T / Cr$  will be always. The difference between the voltages  $V_G$  and  $V_{ref}$  is integrated in a capacitor  $C_{int}$  to obtain a voltage  $V_{cur}$ . Since a certain transitory it is obtained that, at the stationary state,  $V_g = V_{ref}$  and

from this  $I = C_r * V_{ref} * f$ ; therefore it is evident that the current  $I$  is proportional to the frequency  $f = 1/T$ .

From the analysis of the loop gain of the circuit in Figure 1 it is obtained that, by considering the closing delay of the switches 2, 7 or 4,6, the voltage  $V_G$  at the inverting node of the amplifier 8 is  $V_G = I * T * e^{sT} / C_r$  wherein the exponential factor is due to the above mentioned delay. Since  $V_{cur} = V_G / (s * C_{int})$  and  $I = K_c * V_{cur}$  a loop gain for small signals is obtained which is done by:

$$G = \frac{T * e^{sT} * g_m * K_c}{s * C_r * C_{int}}$$

If the effect of the delay is not considered the loop gain  $G$  is a transfer function having a single pole in the origin and a phase margin of  $90^\circ$ . The delay  $e^{sT}$  imposes that the frequency of unitary gain, this is the bandwidth of the circuit, is minor of a fraction of the frequency  $f$ :

$$BW = \frac{g_m * K_c}{2\pi f * C_r * C_{int}} \leq 0,25 * f$$

from this it is obtained the relation:

$$f \geq \sqrt{\frac{2g_m K_c}{\pi C_{int} C_r}}$$

Therefore by means of a frequency  $f$  that respects this inequation a frequency/signal converter is obtained which is stable without compensating.

Alternatively it is possible to insert any integrator instead of the circuit part comprising the transconductance amplifier 8 and the capacitor  $C_{int}$ .

In Figure 4 is shown a switching regulator employing the device in Figure 1. Said regulator comprises a MOS transistor HS having the drain terminal connected with a input voltage  $V_{in}$ , the source terminal connected with a drain terminal of another MOS transistor LS, with the cathode of a diode D1 having the anode connected with ground, with a terminal of an

inductance  $L$ , and the gate terminal connected with a control device 100. The MOS transistor LS has the gate terminal connected with the control device 100 and the source terminal connected with ground. The series of a capacitor  $C_c$  and a resistor  $R$  is placed in parallel with a load LOAD and is connected between the other terminal of the inductance  $L$  and ground. A transconductance error operational amplifier 200 having in input the output voltage  $V_{out}$  at the terminals of the load LOAD and a voltage reference  $V_{ref1}$ , provides a current  $I_2$  that is in input to a current comparator 300 having in input even a signal  $I_1$  representative of the current flowing through the inductance  $L$  and which is obtained by means of a sensing resistor  $R_s$  (this is a resistor adapted to measure the current in the inductance  $L$ ) and a current  $I_{slope}$  provided by a device 101; the output signal  $S$  of the comparator 300 is in input to the control device 100.

Said device 101 has in input a clock signal  $Cl$  and is adapted to determine the duty-cycle  $D$ , that is the on time  $T_{on}$  and the off time  $T_{off}$  in a period  $T_{sw}$  fixed by the clock signal  $Cl$ , so as to drive the transistors HS and LS. The duty-cycle is varied in relation with the input signal  $S$  deriving from the comparator 300.

The device 101 comprises the frequency/signal converter in Figure 1 above described from which a current signal proportional to the frequency  $f$  of the clock signal  $Cl$  is obtained which flows through a circuit comprising a capacitor  $C_{slope}$  and a switch  $St$  arranged in parallel to the capacitor  $C_{slope}$  and driven so as to generate a slope current signal  $I_{slope}$ .

In fact, in order to achieve a good stability of the switching regulator, the inclination of the signal  $I_{slope}$  must be equal to about half the negative inclination of the signal  $I_1$  during the off time  $T_{off}$ , that is the inclination of the discharge of the inductance  $L$  during the  $T_{off}$  time. This can be deduced by analysing the stability of the regulator; in this case a perturbation  $Y$  is introduced in the current flowing through the inductance  $L$  in a certain clock period. At the successive clock period if the regulator is stable the

perturbation  $Y'$  in said current must be lower than  $Y$ . In Figure 5 the theoretical signals  $I_{prog}$  and  $I_1$  for calculating the inclinations, wherein  $I_{prog}$  is obtained by  $I_2 - I_{slope}$ , the values of the perturbations  $Y$  and  $Y'$ , the value  $X$  obtained by the distance between the peaks of the currents  $I_1$  obtained in the two successive clock periods, the rise inclination  $S_r$  and the down inclination  $S_f$  of the current  $I_1$  and the inclination  $Slope$  of the signal  $I_{prog}$  are shown. It is obtained that  $S_r + Slope = Y/X$ ,  $S_f + Slope = Y'/X$  and  $Y'/Y = (S_f - Slope)/(S_r - Slope)$ , also because  $Y' < Y$  it must result  $(S_f - Slope)/(S_r - Slope) < 1$  from which  $Slope > (S_f - S_r)/2$ . Since  $V_{out} = D \cdot V_{in}$  and because  $S_r = (V_{in} - V_{out})/L$  this is  $S_r = V_{in} \cdot (1 - D)/L$  and  $S_f = V_{out}/L$  from which  $S_f = V_{in} \cdot D/L$ , it is obtained that  $Slope > V_{in} \cdot (2D - 1)/(2 \cdot L)$ . The most restrictive condition is obtained by imposing  $D = 1$  from which  $Slope > V_{out}/(2 \cdot L)$  and also  $Slope > S_f/2$ .

Therefore it is achieved:

$$Slope = \frac{V_{out} R_s}{2L}$$
 wherein the inclination of the signal  $I_{slope}$  has been indicated now with  $Slope$ . The value of the inductance  $L$  is forever connected with the regulator switching frequency  $f_{sw}$ ; a switching frequency higher allows to employ an inductance having a lower value, therefore  $L = L_k / f_{sw}$  where  $L_k$  is a proportionality constant. From the above relation it is obtained that  $Slope = K \cdot f_{sw}$  by indicating that  $K = V_{out} \cdot R_s / (2 \cdot L_k)$ . For this reason it is preferably to change the inclination of the slope compensation signal  $I_{slope}$  in a way proportional to the frequency above all in the case of high switching frequencies and the device 101 allows to achieve this. In Figure 6 the waveforms of the signals  $I_1$  and  $I_{prog}$  which are obtained by means of simulations in a circuit as that in Figure 4 are shown wherein the inclination  $Slope$  of the signal  $I_{slope}$  has been imposed equal to at least half the highest discharge inclination  $S_f$  of the current flowing through the inductance  $L$ .



## CLAIMS

1. Frequency/signal converter capable of providing an electric signal ( $V_{cur}$ ) at an output terminal by deriving it from an input clock signal ( $Clk$ ), characterized by comprising first means (1) having said clock signal ( $Clk$ ) in  
5 input and being capable of providing a first ( $PH1$ ) and a second ( $PH2$ ) logic output signals which are complementary with one another, a loop circuit comprising a first (A) and a second (B) circuit lines arranged between a first supply voltage ( $VDD$ ) and a second supply voltage where said first supply voltage ( $VDD$ ) is higher than said second supply voltage and wherein a  
10 current (I) proportional to said output signal ( $V_{cur}$ ) of said converter flows, said first (A) and a second (B) circuit lines comprising respectively first ( $Cr1$ ) and second ( $Cr2$ ) capacitive elements and second (2) and third (4) means which are adapted to interrupt the flow of said current (I) into the capacitive elements and which are controlled by means of said first ( $PH1$ )  
15 and second ( $PH2$ ) logic signals, said first (A) and a second (B) circuit lines being alternatively connected with an input terminal (G) of an integrator device (8,  $C_{int}$ ) by means of other ones of said third (6) and second (7) means in order to obtain at said input terminal (G) a substantially constant voltage signal ( $V_G$ ), said integrator device (8,  $C_{int}$ ) being adapted to  
20 provide said output signal ( $V_{cur}$ ) of the converter.

2. Converter according to claim 1, characterized in that said first ( $PH1$ ) and second ( $PH2$ ) logic signals have a period ( $2T$ ) that is twice the period ( $T$ ) of the input clock signal ( $Clk$ ) and maintain the value one or zero in all the duration of half a period thereof.

25 3. Converter according to claim 1, characterized in that said integrator device (8,  $C_{int}$ ) comprising a transconductance operational amplifier (8) and a further capacitive element ( $C_{int}$ ), said amplifier (8) having said substantially constant voltage signal ( $V_G$ ) at the inverting terminal (-) and a voltage reference ( $V_{ref}$ ) at the non-inverting terminal (+) and being adapted  
30 to provide a current signal at the output terminal which is integrated in said

further capacitive element (Cint) to achieve said output voltage signal (Vcur) of the converter.

5 4. Converter according to claim 1, characterized in that said first (A) and a second (B) circuit lines comprising further fifth (3) and sixth (5) means adapted to discharge said first (Cr1) and second (Cr2) capacitive elements, said further fifth (3) and sixth (5) means being controlled by means of further pulse signals (RESET1, RESET2) sensitive to the rise fronts of said first (PH1) and second (PH2) logic signals.

10 5. Switching regulator capable to provide a regulated voltage (Vout) at an output terminal to a load (LOAD), said regulator comprising a transistor (HS) coupled with an input terminal (Vin) and with said output terminal, at least one inductance (L) coupled with an output terminal of said transistor and with said output terminal of the regulator, first circuit means (200) coupled with said output terminal and adapted to provide a feedback signal  
15 (I2) representative of said regulated voltage, second circuit means (Rs) coupled with said inductance (L) and capable to provide a signal (I1) representative of the current signal flowing through said inductance (L), a control circuit (100) coupled with said first (200) and said second (Rs) circuit means and with said transistor (HS) and having an input clock signal  
20 (Cl), said control circuit (100) being adapted to drive said transistor (HS) in order to interrupt a current flow from said input terminal (Vin) to said output terminal according to a prefixed duty-cycle (D), characterized by comprising a device (101) having in input said clock signal (Cl) and adapted to generate in output a slope compensation signal (Islope) proportional to the frequency  
25 (fsw) of said clock signal (Cl) when said duty-cycle exceeds a prefixed value, said slope compensation signal (Islope) being in input to said control circuit (100).

30 6. Regulator according to claim 5, characterized by comprising a comparator (300) adapted to compare a signal (Iprog) obtained by the sum of said feedback signal (I2) and of said slope compensation signal (Islope)



and said signal (I1) representative of the current signal flowing through the inductance (L), said comparator (300) providing a signal (S) to said control circuit (100).

5 7. Regulator according to claim 5, characterized in that said device (101) comprises a frequency/signal converter comprising first means (1) having said clock signal (Cl) in input and being capable of providing a first (PH1) and a second (PH2) logic output signals which are complementary with one another, a loop circuit comprising a first (A) and a second (B) circuit lines arranged between a first supply voltage (VDD) and a second  
10 supply voltage where said first supply voltage (VDD) is higher than said second supply voltage and wherein a current (I) proportional to said output signal (Vcur) of said converter flows, said first (A) and a second (B) circuit lines comprising respectively first (Cr1) and second (Cr2) capacitive elements and second (2) and third (4) means which are adapted to interrupt  
15 the flow of said current (I) into the capacitive elements and which are controlled by means of said first (PH1) and second (PH2) logic signals, said first (A) and a second (B) circuit lines being alternatively connected with an input terminal (G) of an integrator device (8, Cint) by means of other one of said third (6) and second (7) means in order to obtain at said input terminal  
20 (G) a substantially constant voltage signal (VG), said integrator device (8, Cint) being adapted to provide said output signal (Vcur) of the converter.

8. Regulator according to claim 7, characterized in that said first (PH1) and second (PH2) logic signals have a period ( $2T_{sw}$ ) that is twice the period ( $T_{sw}$ ) of the input clock signal (Cl) and maintain the value one or zero in all  
25 the duration of half a period thereof.

9. Regulator according to claim 7, characterized in that said integrator device (8, Cint) comprising a transconductance operational amplifier (8) and a further capacitive element (Cint), said amplifier (8) having said  
30 substantially constant voltage signal (VG) at the inverting terminal (-) and a voltage reference (Vref) at the non-inverting terminal (+) and being adapted

to provide a current signal at the output terminal which is integrated in said further capacitive element (Cint) to achieve said output voltage signal (Vcur) of the converter.

10. Regulator according to claim 7, characterized in that said first (A)  
5 and a second (B) circuit lines comprising further fifth (3) and sixth (5) means adapted to discharge said first (Cr1) and second (Cr2) capacitive elements, said further fifth (3) and sixth (5) means being controlled by means of further pulse signals (RESET1, RESET2) sensitive to the rise  
10 fronts of said first (PH1) and second (PH2) logic signals.

"Frequency/signal converter and switching regulator employing said converter."

\* \* \* \* \*

#### ABSTRACT

5           A frequency/signal converter capable of providing an electric signal  
(V<sub>cur</sub>) at an output terminal by deriving it from an input clock signal (Clk)  
is disclosed. The converter comprises first means (1) having said clock  
signal (Clk) in input and being capable of providing a first (PH1) and a  
10           second (PH2) logic output signals which are complementary with one  
another, a loop circuit comprising a first (A) and a second (B) circuit lines  
arranged between a first supply voltage (VDD) and a second supply voltage  
where said first supply voltage (VDD) is higher than said second supply  
voltage and wherein a current (I) proportional to said output signal (V<sub>cur</sub>) of  
the converter flows. The first (A) and a second (B) circuit lines comprise  
15           respectively first (Cr1) and second (Cr2) capacitive elements and second (2)  
and third (4) means which are adapted to interrupt the flow of said current  
(I) into the capacitive elements and which are controlled by means of the  
first (PH1) and second (PH2) logic signals. The first (A) and a second (B)  
circuit lines are alternatively connected with an input terminal (G) of an  
20           integrator device (8, C<sub>int</sub>) by means of other ones of said third (6) and  
second (7) means in order to obtain at said input terminal (G) a substantially  
constant voltage signal (V<sub>G</sub>). The integrator device (8, C<sub>int</sub>) is adapted to  
provide the output signal (V<sub>cur</sub>) of the converter. (Figure 1)



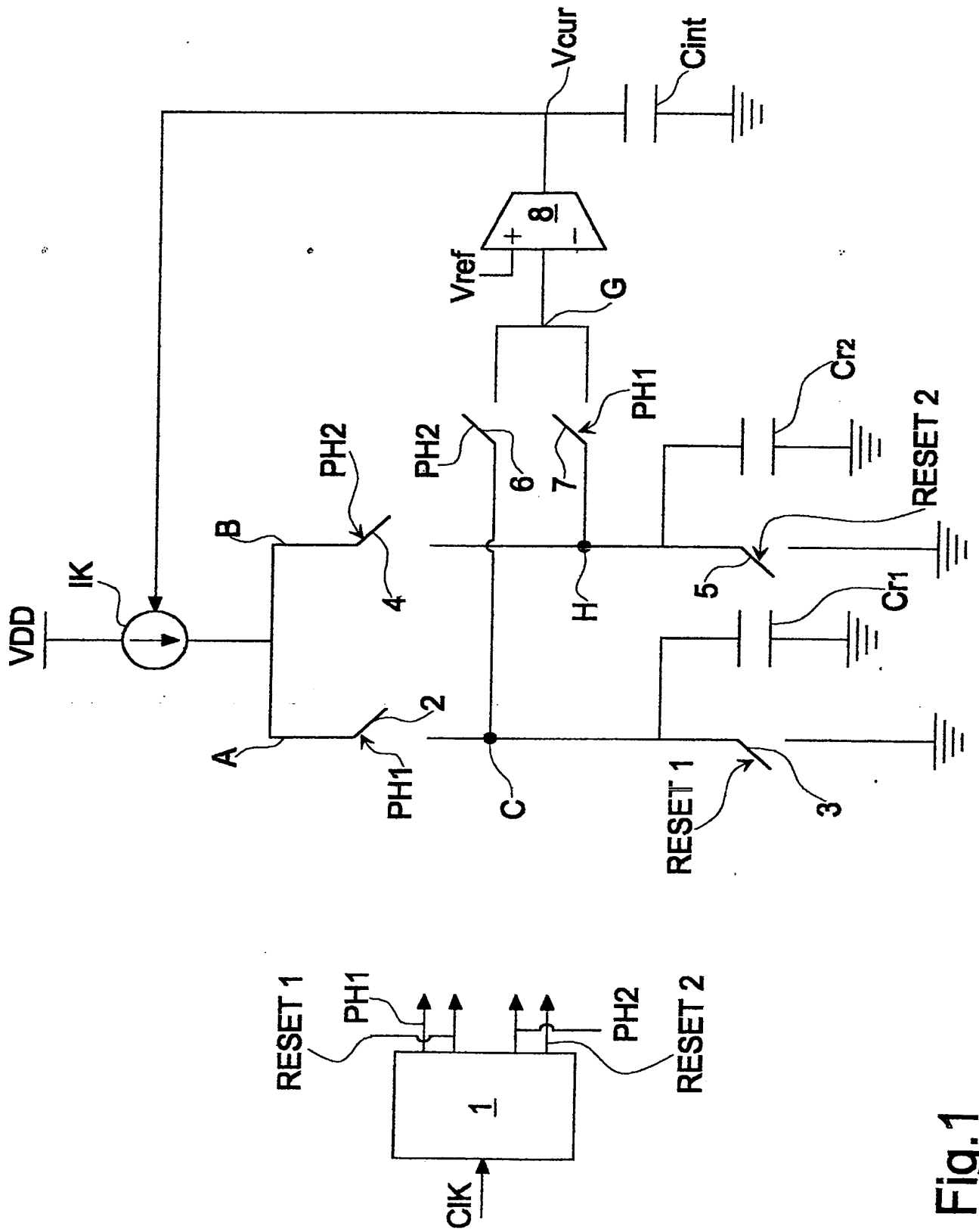


Fig.1

2/5

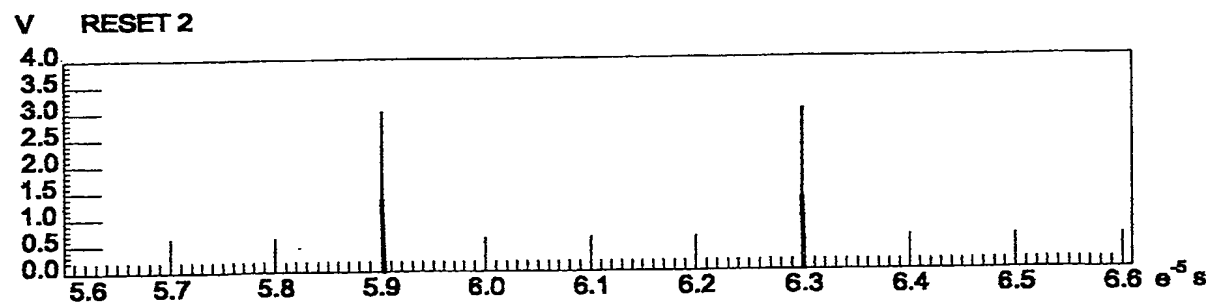
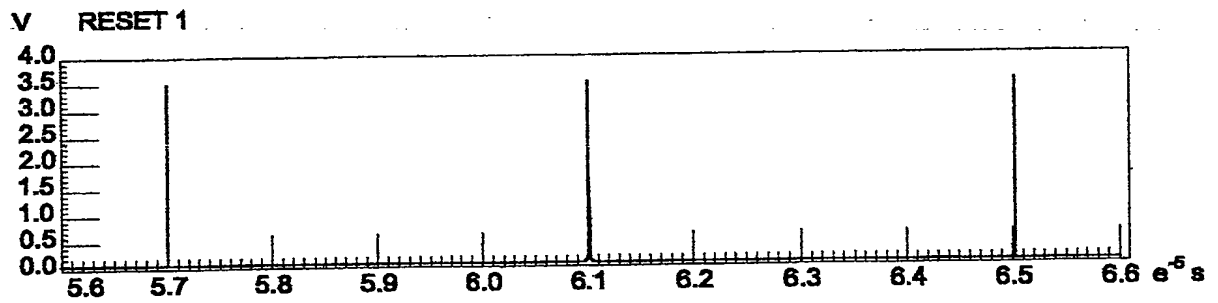
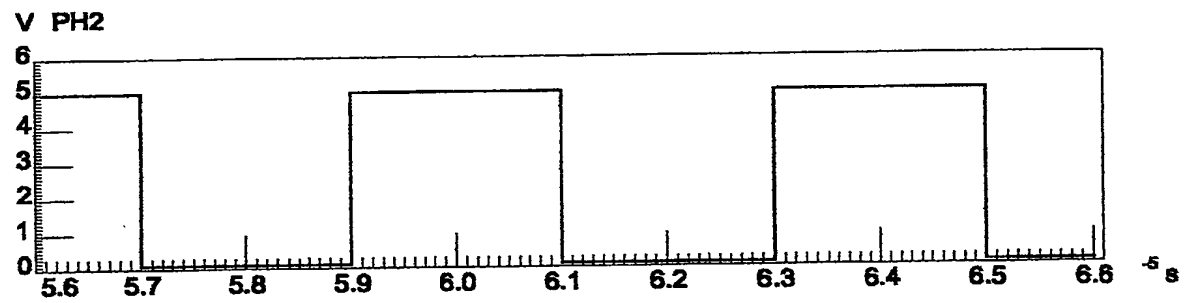
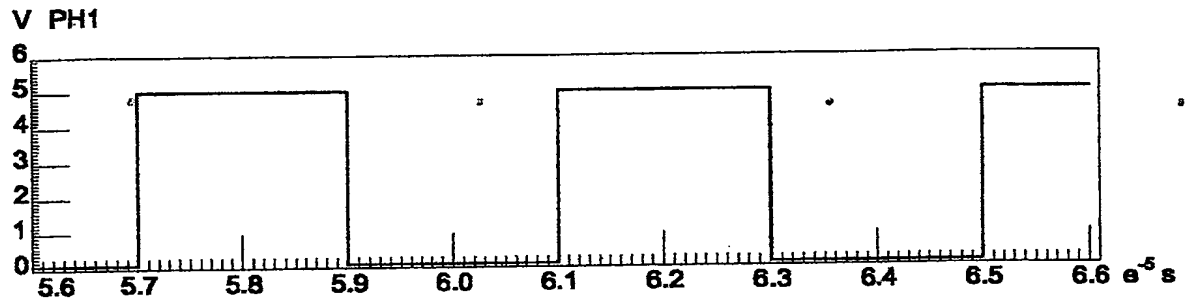
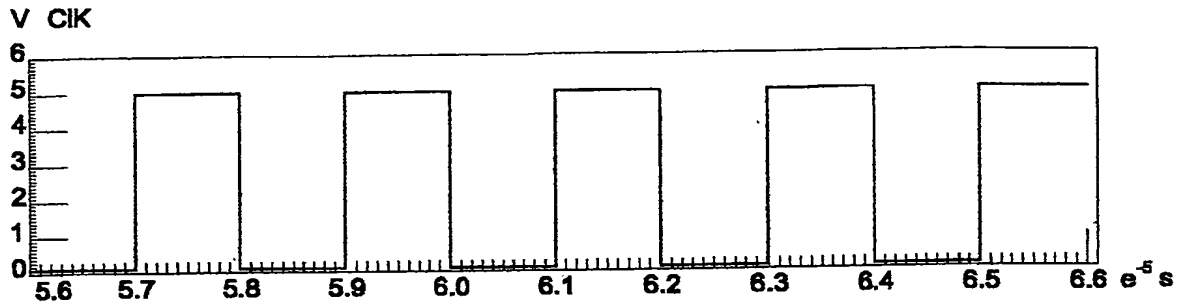


Fig.2

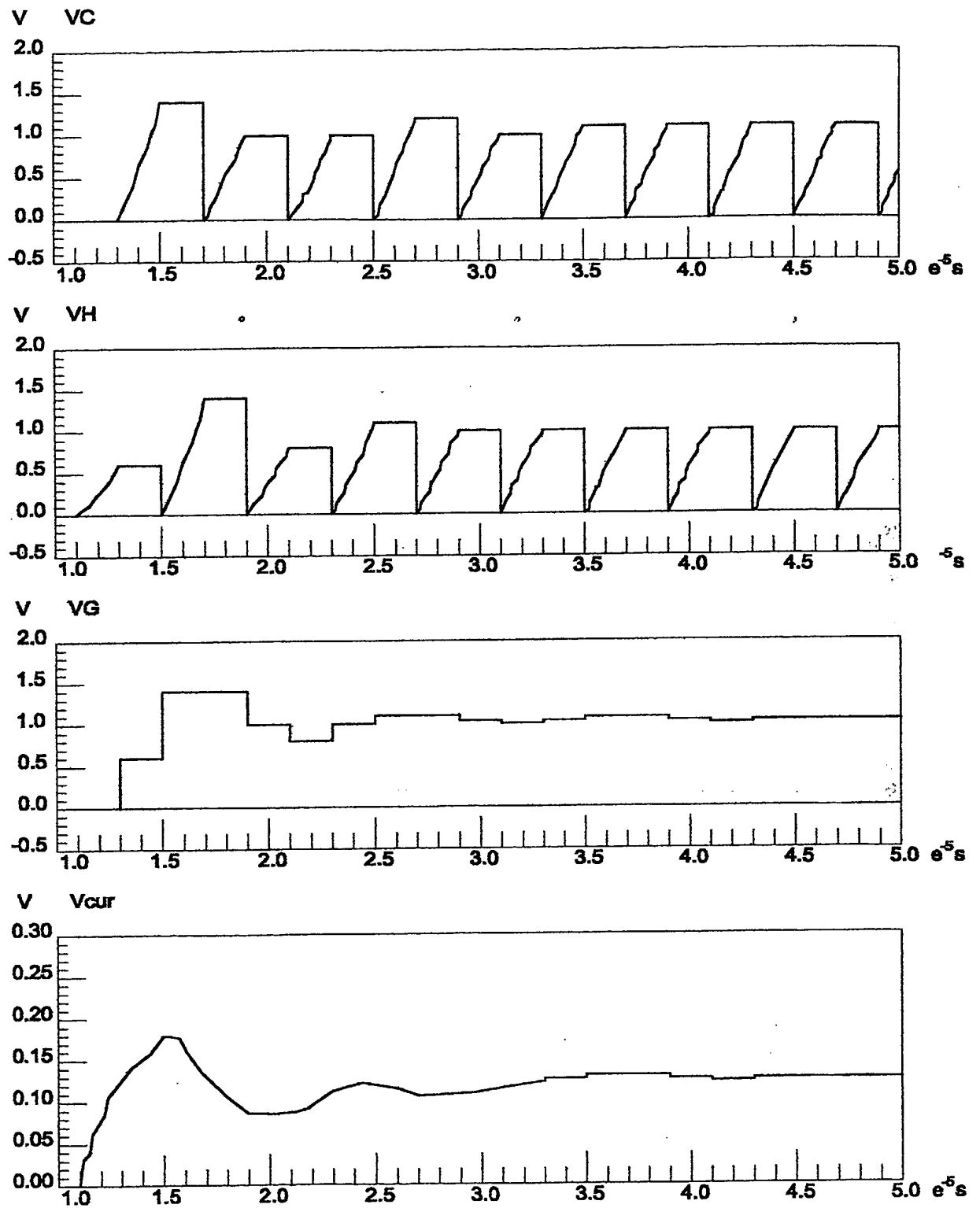


Fig.3





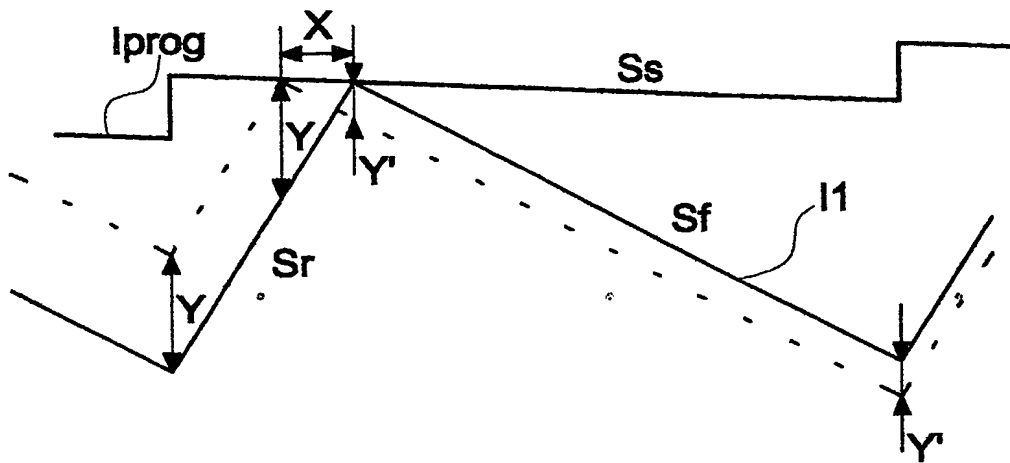


Fig.5

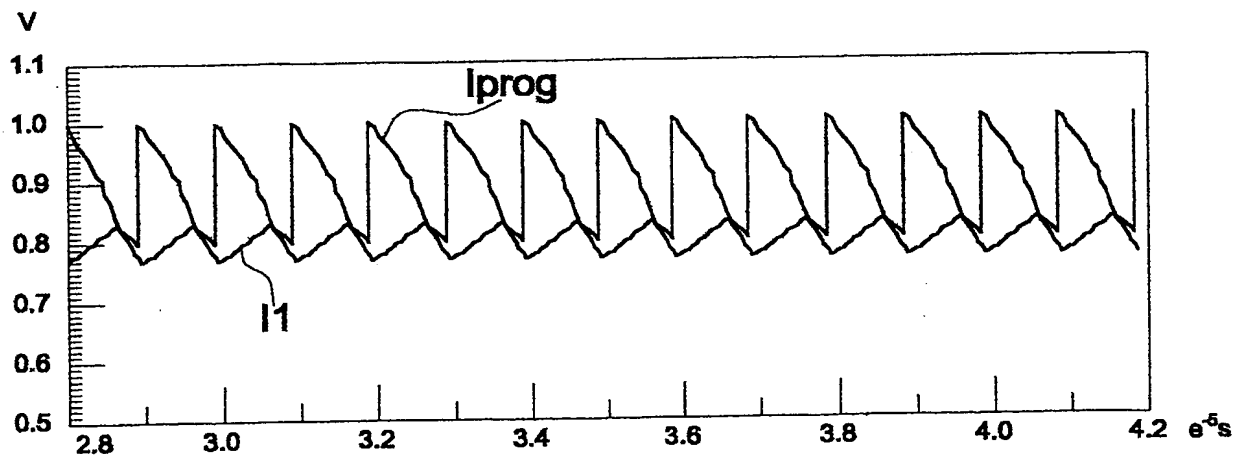


Fig.6

Post